A DESIGN TOOL FOR INTERIOR DAYLIGHTING
DESCRIPTION OF LUMINOUS ENVIRONMENT WITH IMAGE SYNTHESIS

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ABSTRACT

As part of visualization of interior luminous environment in daylighting a **programme (NATUREL)** has been developed at CSTB. It allows to take into account complex shapes of building, furniture and apertures. These, located on facade and/or on roofing, are characterized with various parameters : area, thickness of wall (roof), luminous transmission, outdoor surroundings ... All surfaces (indoor and outdoor) of the scene are described in term of plane facets and are supposed to have perfectly diffuse reflection, which is advised for interior lighting.

The software includes three main steps

Calculation of the direct component of illuminances (light arising from *exterior : sun* + sky + ground + buildings). This calculation is made at points which are determined to take into account the luminous gradients on the surfaces. These gradients are due to sunspot and to geometric interaction between apertures and furniture (umbra and penumbra zones).

Calculation of *interreflections.* Interreflections are estimated by using the radiosity method.

Visualization on graphic colour VDU. Two stages are necessary : a graphical calculation (projection along a given direction), and a colorimetric calculation.

In a first time this method has been applied to "grey" surfaces. Then the spectral properties have been taken into account for the incident light, transmission of glazing materials and reflection of various surfaces.

DAYLIGHTING AND NUMERICAL SIMULATION

The study of interior daylighting consists in characterizing light distribution inside building. This can be made in two ways : levels and contrasts of illuminance (or luminance) . Another objective for such a study can also be to optimize position of apertures. Results are used for improvement of visual comfort and have to be taken into account (in term of consequence on use of artificial lighting) in the global energetic balance.

To process a daylighting study three main means are usable : field measurements, scale model measurements (inside an Artificial Sky) and numerical simulation. The two first one allow to take into account (completely or partly for scale-models) building characteristics but they depend on outside luminous characteristics (real or simulated).

By using numerical simulation, it is possible to have various outside conditions but it is more difficult to obtain a perfect reproduction of the scene. In a first step calculation units have been perfected for an empty parallelepipedic room and for grey surfaces. Then the method has been extended to premises of any shape and with possibility of furniture (Le Strat 1990). Spectral calculations are also carried out.

LIMITS OF THE SOFTWARE AND INPUT DATA

In the present version, the program is usable for premises of any shape lighted by apertures which can be so many than wanted. These apertures have polygonal shapes. The interior of the premises can be equipped with polyhedric volumes. There are two main restrictions regarding the premises : curved surfaces have to be considered as set of polygons plane surfaces and all surfaces of the scene are supposed to be perfectly diffusing, which is advised for a good lighting. Characteristics of the luminous source (sky for overcast condition or sky plus sun for clear and intermediate conditions) are selected among normalized sky luminance distributions and any other distributions. These last can be discrete or continuous. For spectral calculation the colour of interior surface is given with CIE trichromatic coordinates x, y and Y.

GEOMETRICAL DESCRIPTION OF THE SCENE

According to geometries of building and furniture which are generally found, the scene is described as a group of three basic polyhedrons : parallelepiped, triangular basis prism and tetrahedron. Each of these polyhedrons is characterized with several parameters :
- coordinates of four vertex
- nature (transparency or opacity) and physical properties (colour, reflection or transmission factor) of each plane surface

Polyhedrons, defined as polygonal surfaces, are intended to be inserted in a scene, and, using assemblist process, to fill or to create space. So another parameter has to be added to those described above.

Successive integration of all polyhedrons leads to give a new definition of the set of polygons in term of convex polygons.

OPTIMIZATION OF CALCULATION

Two aspects of daylighting induce to modify initial polygons : sunspots (when they exist) and umbra zones resulting from interaction between light emitted by large source (sky or/and outdoor environment seen through the aperture) and various surfaces of the scene. In a first time these zones are only processed in a geometrical point of view.

Sunspots determination

This determination is done in two steps. The first one is the projection of the aperture polygon on the whole polygons of the scene. These one are taken independently of each other. Then really sunny zones are obtained with series of projections starting from the sunny polygon which is the nearest from the aperture. Afterwards, in the illuminance calculation step, the direct component of the illuminance which will be set to these zones, will fit only to the sun. The value of the illuminance will depend on orientation of the surface in relation to the sun position.

Umbra zones determination

Algorithms for umbra zones determination which can be used for image synthesis are, in most of cases, applicable for ray-tracing method which fit to luminous sources. In the general case a daylighting study requires to take into account large luminous sources (the apertures). The method which is used is based on an algorithm (Nishita and Nakamae 1983) applicable to convex occulting volumes.

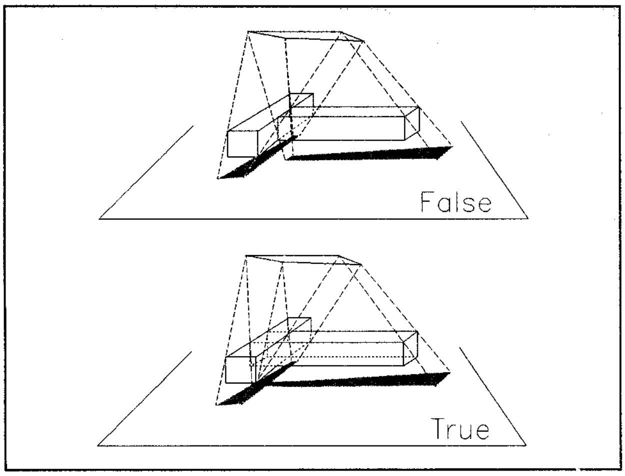

Fig. 1 - Umbra zones for two contiguous polyhedrons

When two convex volumes are contiguous it is necessary to insert an additional step : the concave envelope of the these two volumes has to be decomposed into two convex volumes which are limited by the envelope. The umbra zone resulting from this step is obtained by complementation of the two zones due to the two new volumes (Figure 1). No calculation of direct component illuminance will be done on these zones. Only inter-reflected component will be calculated.

Calculation grid

In order to minimize the number of calculation points while keeping an acceptable rendering of daylighting, the calculation grid has been optimized.

S : total area of all interior surfaces
N : approximate number of grid cell (input data)
--> Se : mean area of the grid cells
--> regular grid on each polygon
• : calculation point

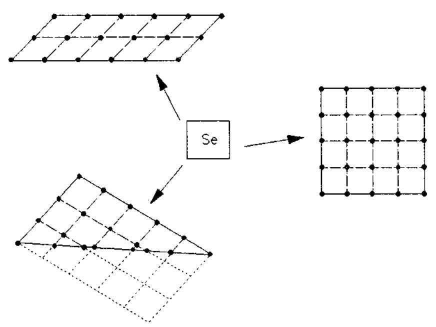

Fig. 2 - Regular grid for basis surfaces

The two previous aspects of daylighting (sunspots and umbra zones) contribute to this optimization and to the obtaining of a final image as realistic as possible.

The polygonal facets of the initial polyhedrons are either parallelograms or triangles. A regular grid is associated to these facets (Figure 2). Characteristics of the grid depend on the area and on the ratio of the two main dimensions. After construction of the scene and determination of sunspots and umbra zones, some initial grid elements disappear and some others are added (Figure 3).

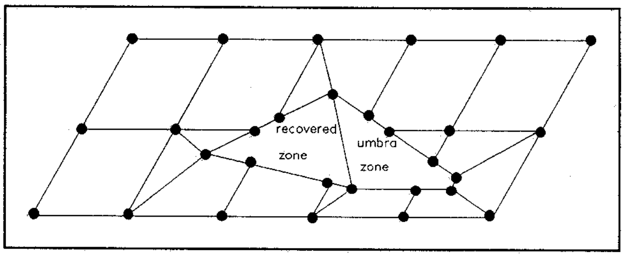

Fig. 3 - Calculation grid for modified surface

ILLUMINANCE CALCULATION

In daylighting of premises, illuminance can be decomposed into three components (Figure 4) :

- SC : sky component (light coming directly from sky and sun)
- ERC : external reflected component (light coming from reflections on external surfaces like ground and buildings)
- IRC : internal reflected component (interreflections inside the premises)

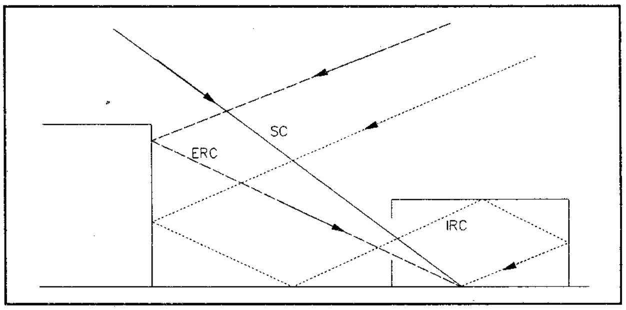

Fig. 4 - Interior daylighting components

From these three components and the assumption of perfectly diffuse reflection an appropriate method is to be used : the radiosity method. Global internal illuminances will be obtained in two steps :

- calculation of "direct" illuminance (sky component plus external reflected component)
- calculation of interreflections

"Direct" Illuminances

Sky Component. The general relation between illuminance E on any plane, at a point P and sky luminance L is the following :

$$E_P = \int_{\alpha_1}^{\alpha_2} \int_{\theta_1}^{\theta_2} L(\alpha,\theta) \cos\theta \cos\eta \, d\theta \, d\alpha$$

where α and Θ are defined on Figure 5
η depends on α and Θ and surface orientation
α_1, α_2, θ_1 and θ_2 delimit the part of sky which is seen through the aperture

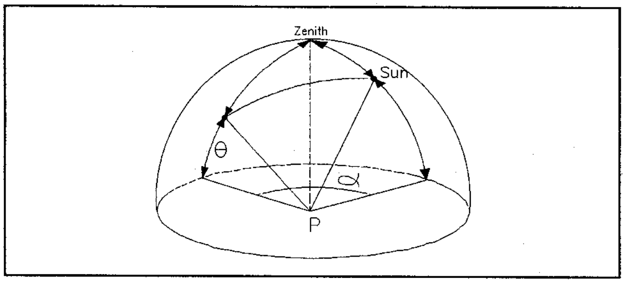

Fig. 5 - Angles used for sky luminance distribution

At the present time there are three normalized sky luminance distributions (International Commission on Illumination) :

- uniform overcast sky ($L(\alpha,\theta)=L_a$)
- Moon & Spencer overcast sky ($L(\alpha,\theta)=L_z\cdot(1+2\sin\theta)/3$ with L_z = zenith luminance)
- CIE Clear sky ($L(\alpha,\theta)$ depends on sun position) (CIE 1973)

Other discrete or continuous sky luminance distributions can be used. It is the case of these related to intermediate skies (sun + partly cloudy sky).

Because of the polygonal shape of the apertures, summation has been preferred to integration. To do this summation, the aperture is divided into small elements. The number of these elements is linked to the solid angle Ω under which the aperture is seen from the calculation point :

- 16 elements if $\Omega \leq 0{,}7$ sr
- 64 elements if $0{,}7 \text{ sr} < \Omega \leq 1{,}5$ sr
- 256 elements if $1{,}5 \text{ sr} < \Omega$

At each element of the summation is associated the value of the luminance of the sky seen through the centre of the element multiplied by transmission factor for the corresponding incidence. Generally in lighting an integrated factor is used : *diffuse incidence transmission factor* (for a material lighted by a large source). This mean value is independent of the incidence of observation.

For the calculation points which are located near the aperture, illuminance is obtained, after sky discretization into 256 zones seen under the same solid angle (0,00237 sr). Therefore a summation is done on the zones which light the point.

External reflected component. The determination of this component is done using ground and building luminances. The luminance L is deduced from illuminance E on the same surface, with the assumption of perfectly diffusing surface. So the following formula is used : $L=\rho E/\Pi$ where ρ is the diffuse reflection factor of the surface.

INTERREFLECTIONS

The radiosity method requires the knowledge of form factors between the various surfaces of the scene. They have been obtained using a projection (Sillion 1989) based on the Nusselt analog (Cohen and Greenberg 1985). This projection system (Figure 6) uses two quantities d and h. Because of this length h, the whole polygons of the scene are not taken into account when the scene is projected on the 2d length square. If the ration d/h is about 14, the error is about 1 %. Actually, the projection square is not divided in identical surface elements but in elements which are seen under the same solid angle from the center of the patch. Interreflections calculated for one patch give a mean value which is added to the direct component of illuminance of each corner of the patch.

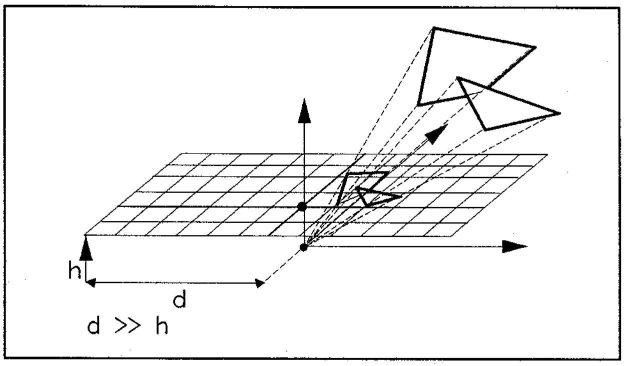

Fig. 6 - Form-factor calculation. Single projection

COLOUR DETERMINATION

To obtain data regarding colour which is perceived inside the premise spectral point of view has to be integrated into the daylighting process : luminous source, transmission through the glazing materials and reflection on indoor surfaces.

Luminous source

Spectral distribution of daylight have been normalized, after many measurements, by the International Commission on Illumination. One of these normalized distributions is the standard illuminant D_{65} (CIE 1986) with a colour temperature of 6554°K (Figure 7).

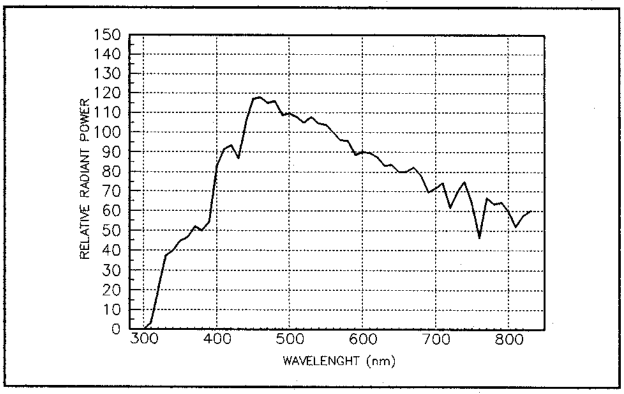

Fig. 7 - Relative spectral distribution of illuminant D_{65}

Transmission through glass materials

Instead a mean transmission factor, spectral transmissions factors are applied to the incident light on the glasses. For a plastic glass material the spectral factor is this of the Figure 8.

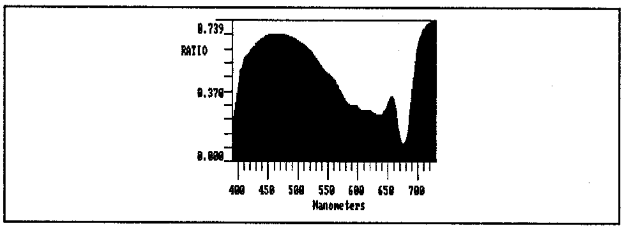

Fig. 8 - Example of spectral transmission

Coloured interreflexions

To estimate coloured interreflexions the reflection factor of each interior surface has been expressed with only three components which are associated to the three parts of the spectrum linked to the phosphorous of the CRT of the VDU.

The objective of this process is to obtain colours which appear identical with the D_{65} spectrum and the three band spectrum (metamerism phenomena). The radiosity method is applied for each of the three bands of the spectrum. Final results are expressed in term of red, green and blue component for each point of the calculation grid.

VALIDATION OF THE MODEL

The validation has been made with a scale model lighted in the Artificial Sky of CSTB. Geometrical characteristics of the building which has been tested are given on Figure 9. The internal surfaces of the model are grey.

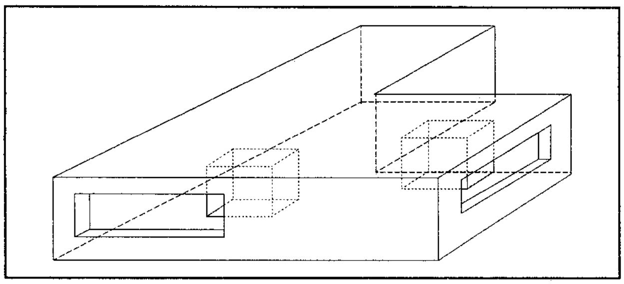

Fig. 9 - Test room

Direct component of illuminances

The comparison is done without glass materials, and without spectral calculation. The maximal error is about 5 %. This can be explain by the luminance distribution in the Artificial Sky and the discretization of the aperture. Luminance distribution which is used is Moon & Spencer overcast sky, but in the Artificial Sky the distribution is this one with an approximation. Figure 10 presents one image obtained with only direct component of illuminances.

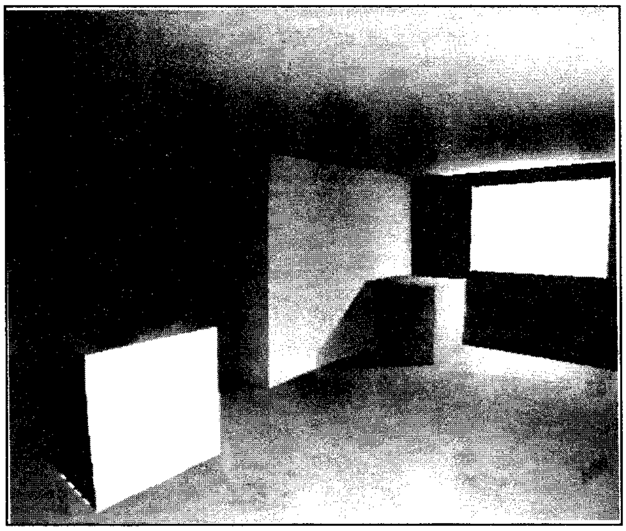

Fig. 10 - Direct component of illuminances (results from calculation)

Global illuminance with coloured surfaces

Four walls have been painted (green, yellow, blue and red) and the other surfaces are the same than above (grey). Comparison is not so good than for the direct component. There are two main reasons : the projection for calculation of form factors and the spectral characteristics of the Artificial Sky (light source is fluorescent lamp) do not fit to the D_{65} illuminant. Nevertheless calculated values are in agreement with measured colours.

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